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(54) HEAT EXCHANGER AND HEAT PUMP USING SAME

(57) A heat exchanger 100 includes a plurality of heat exchange segments 10. Each of the heat exchange segments 10 is composed of an inner tube assembly 26 including two inner tubes 24, and an outer tube 28. A gap width G represented by a difference $((\phi_{in} / 2) - \phi_{out})$ between a half of an inner diameter ϕ_{in} of the outer tube 28 and an outer diameter ϕ_{out} of the inner tube 24 satisfies $0 < G \leq 0.8$ (unit: mm). A path number N indicating the number of the heat exchange segments 10 and the inner diameter ϕ_{in} (unit: mm) of the outer tube 28 satisfy one of relationships (1) to (5) below. (1) $N = 4$ and $8.20 \leq \phi_{in} \leq 9.50$ (2) $N = 5$ and $7.58 \leq \phi_{in} \leq 8.90$ (3) $N = 6$ and $7.14 \leq \phi_{in} \leq 8.50$ (4) $N = 7$ and $6.78 \leq \phi_{in} \leq 8.20$ (5) $N = 8$ and $6.52 \leq \phi_{in} \leq 7.90$

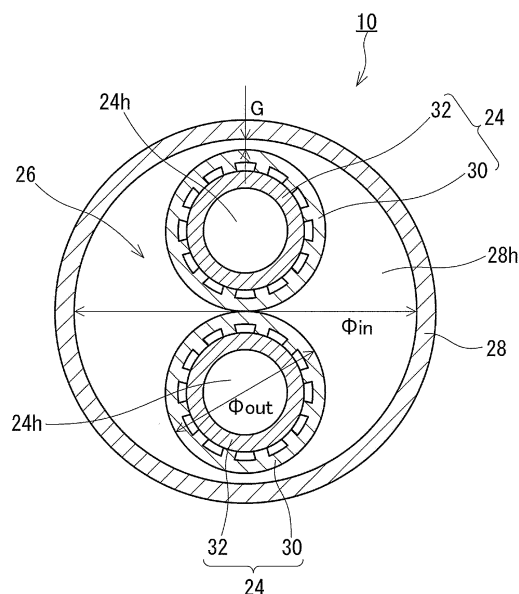


FIG.2

Description

TECHNICAL FIELD

5 **[0001]** The present invention relates to a heat exchanger and a heat pump including the heat exchanger.

BACKGROUND ART

10 **[0002]** Conventionally, heat exchangers for exchanging heat between two kinds of fluids (water and a refrigerant, or air and a refrigerant, for example) have been used widely.

[0003] For example, Patent Literature 1 describes a double tube heat exchanger including inner tubes and outer tubes. As described in FIG. 6 of Patent Literature 1, the heat exchanger of Patent Literature 1 includes two double tubes and a header. The header connects the two double tubes in parallel. The double tubes each are composed of one outer tube and two inner tubes.

15 **[0004]** Patent Literature 2 describes a heat exchanger including a housing having a rectangular flow passage, and heat transfer tubes disposed in the flow passage inside the housing. The heat exchanger described in Patent Literature 2 is the same as the heat exchanger described in Patent Literature 1 in that it has a configuration in which the tube having the flow passage for one fluid is disposed in the flow passage for another fluid.

20 **[0005]** In this specification, a heat exchanger having a configuration in which a flow passage for one fluid is disposed in a flow passage for another fluid is referred to as "a double flow passage heat exchanger".

CITATION LIST

Patent Literature

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[0006]

PLT 1: JP 4414197 B

PLT 2: JP 2005-24109 A

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SUMMARY OF INVENTION

Technical Problem

35 **[0007]** The heat exchangers described in Patent Literatures 1 and 2 are very heavy because they are made of metal such as copper and stainless steel. Thus, a lighter-weight double flow passage heat exchanger is desired.

[0008] In view of the foregoing, the present invention is intended to provide a technique for reducing the weight of a double flow passage heat exchanger.

Solution to Problem

40 **[0009]** That is, the present disclosure provides a heat exchanger for exchanging heat between a first fluid and a second fluid, including:

45 a plurality of heat exchange segments each having a first flow passage and a second flow passage;
a first header provided at one end of the heat exchange segments so that the first fluid is introduced into the first flow passage and the second fluid is collected from the second flow passage; and
a second header provided at another end of the heat exchange segments so that the first fluid is collected from the first flow passage and the second fluid is introduced into the second flow passage.

50 Each of the heat exchange segments is composed of (i) an inner tube assembly that includes two inner tubes each having the first flow passage and that is formed of the two inner tubes twisted spirally, and (ii) an exterior body accommodating the inner tube assembly so that the second flow passage is formed between an inner circumferential surface of the exterior body and an outer circumferential surface of the inner tube assembly.

A path number N indicating the number of the heat exchange segments disposed between the first header and the second header is 4 to 8.

55 A gap width G represented by a difference $((\phi_{in} / 2) - \phi_{out})$ between a half of an inner diameter ϕ_{in} of the exterior body and an outer diameter ϕ_{out} of the inner tube satisfies $0 < G \leq 0.8$ (unit: mm).

[0010] The path number N and the inner diameter ϕ_{in} (unit: mm) of the exterior body satisfy one of relationships (1) to (5) below.

$$(1) N = 4 \text{ and } 8.20 \leq \phi_{in} \leq 9.50$$

$$(2) N = 5 \text{ and } 7.58 \leq \phi_{in} \leq 8.90$$

$$(3) N = 6 \text{ and } 7.14 \leq \phi_{in} \leq 8.50$$

$$(4) N = 7 \text{ and } 6.78 \leq \phi_{in} \leq 8.20$$

$$(5) N = 8 \text{ and } 6.52 \leq \phi_{in} \leq 7.90$$

Advantageous Effects of Invention

[0011] By determining appropriately the relationship among the inner diameter ϕ_{in} of the exterior body, the gap width G and the path number N, the present disclosure makes it possible to provide a heat exchanger having a reduced weight even while having a heat exchanging capacity equivalent to those of conventional double flow passage heat exchangers.

Brief Description of Drawings

[0012]

FIG. 1 is a schematic plan view of a heat exchanger according to one embodiment of the present invention.
 FIG. 2 is a cross-sectional view of a heat exchange segment used in the heat exchanger shown in FIG. 1.
 FIG. 3 is a schematic view of an inner tube assembly.
 FIG. 4 is a configuration diagram of a heat pump water heater.
 FIG. 5 is a graph showing simulation results.
 FIG. 6 is another graph showing simulation results.
 FIG. 7 is still another graph showing simulation results.
 FIG. 8 is still another graph showing simulation results.

DESCRIPTION OF EMBODIMENTS

[0013] The heat exchanger of Patent Literature 1 has large dimensions despite its heat exchanging capacity because it has a large space at its center (see FIG. 3, etc.) The dimensions of the heat exchanger of Patent Literature 1 are affected significantly by the curvature radii of corner portions, for example. Smaller curvature radii of the corner portions can make the overall dimensions smaller. However, the curvature radii of the corner portions have an inevitable limit in accordance with the size of the double tubes, etc. This makes it almost impossible to reduce further the weight of the heat exchanger by contriving the bending shape of the double tubes.

[0014] The present inventors investigated, through computer simulation, how the weight of the heat exchanger changes when the number of the flow passages in the double flow passage heat exchanger (corresponding to the number of the double tubes in Patent Literature 1), the inner diameter of the outer tube, and the width of the gap between the outer tube and the inner tube are changed while the heat exchanging capacity is kept at a fixed value. As a result, they have found it possible to reduce the weight of the heat exchanger when the number of the flow passages, the inner diameter of the outer tube, and the gap width take specific values, respectively. Based on this finding, the present inventors disclose the following.

[0015] A first aspect of the present disclosure provides a heat exchanger for exchanging heat between a first fluid and a second fluid, including:

a plurality of heat exchange segments each having a first flow passage and a second flow passage;
 a first header provided at one end of the heat exchange segments so that the first fluid is introduced into the first

flow passage and the second fluid is collected from the second flow passage; and a second header provided at another end of the heat exchange segments so that the first fluid is collected from the first flow passage and the second fluid is introduced into the second flow passage.

[0016] Each of the heat exchange segments is composed of (i) an inner tube assembly that includes two inner tubes each having the first flow passage and that is formed of the two inner tubes twisted spirally, and (ii) an exterior body accommodating the inner tube assembly so that the second flow passage is formed between an inner circumferential surface of the exterior body and an outer circumferential surface of the inner tube assembly.

[0017] A path number N indicating the number of the heat exchange segments disposed between the first header and the second header is 4 to 8.

[0018] A gap width G represented by a difference $((\phi_{in} / 2) - \phi_{out})$ between a half of an inner diameter ϕ_{in} of the exterior body and an outer diameter ϕ_{out} of the inner tube satisfies $0 < G \leq 0.8$ (unit: mm).

[0019] The path number N and the inner diameter ϕ_{in} (unit: mm) of the exterior body satisfy one of relationships (1) to (5) below.

$$(1) N = 4 \text{ and } 8.20 \leq \phi_{in} \leq 9.50$$

$$(2) N = 5 \text{ and } 7.58 \leq \phi_{in} \leq 8.90$$

$$(3) N = 6 \text{ and } 7.14 \leq \phi_{in} \leq 8.50$$

$$(4) N = 7 \text{ and } 6.78 \leq \phi_{in} \leq 8.20$$

$$(5) N = 8 \text{ and } 6.52 \leq \phi_{in} \leq 7.90$$

[0020] A second aspect of the present disclosure provides the heat exchanger as set forth in the first aspect, wherein the gap width G satisfies $0.16 \leq G \leq 0.8$. This makes it possible to put smoothly the inner tube assembly into the exterior body.

[0021] A third aspect of the present disclosure provides the heat exchanger as set forth in the first aspect or the second aspect, wherein the inner tubes and the exterior body each are composed of a copper tube. This makes it possible to exchange heat between the first fluid and the second fluid efficiently.

[0022] A fourth aspect of the present disclosure provides the heat exchanger as set forth in the first aspect or the second aspect, wherein the inner tubes each are composed of a copper tube and the exterior body is made of a resin. The exterior body made of a resin may make it possible to provide a heat exchanger having a further reduced weight.

[0023] A fifth aspect of the present disclosure provides the heat exchanger as set forth in any one of the first to fourth aspects, wherein the inner tubes each are a leakage detection tube composed of a smooth-inner-surface tube and an inner-surface-grooved tube provided outside around the smooth-inner-surface tube. The leakage detection tube can prevent the first fluid from flowing into the second flow passage even in the case where the smooth-inner-surface tube is damaged.

[0024] A sixth aspect of the present disclosure provides the heat exchanger as set forth in any one of the first to fifth aspects, wherein the first fluid is carbon dioxide and the second fluid is water. Use of carbon dioxide as a refrigerant allows to heat the water to a temperature close to its boiling point.

[0025] A seventh aspect of the present disclosure provides a heat pump including:

a compressor for compressing a refrigerant;

a radiator for cooling the compressed refrigerant, the radiator being composed of any one of the heat exchangers as set forth in the first to sixth aspects;

an expansion mechanism for expanding the cooled refrigerant;

an evaporator for evaporating the expanded refrigerant; and

a water circuit for circulating water through the radiator.

[0026] Use of any one of the heat exchangers as set forth in the first to sixth aspects makes it possible to increase

the efficiency of the heat pump.

[0027] Hereinafter, embodiments of the present invention are described with reference to the drawings. The present invention is not limited by the following embodiments.

[0028] As shown in FIG. 1, a heat exchanger 100 of the present embodiment includes a plurality of heat exchange segments 10, a first header 16 and a second header 22. The first header 16 and the second header 22 are provided respectively at one end and another end of the heat exchange segments 10.

[0029] As shown in FIG. 2, each of the heat exchange segments 10 is composed of an inner tube assembly 26 and an outer tube 28 (exterior body). The inner tube assembly 26 includes two inner tubes 24. The two inner tubes 24 each have a first flow passage 24h. As shown in FIG. 3, the inner tube assembly 26 is formed of the two inner tubes 24 twisted spirally. The inner tube assembly 26 is disposed in the outer tube 28. Thereby, a second flow passage 28h is formed between an inner circumferential surface of the outer tube 28 and an outer circumferential surface of the inner tube assembly 26. Typically, the first flow passage 24h and the second flow passage 28h each have a circular cross-sectional shape.

[0030] A helical pitch and helix angle of the inner tube assembly 26 are not particularly limited. The helical pitch is adjusted to fall in the range of 20 to 65 mm, for example. The helix angle is adjusted to fall in the range of 13 to 26°, for example. A somewhat large helix angle is desirable, but there is a processing limitation in accordance with an outer diameter of each inner tube 24. As shown in FIG. 3, the "helical pitch" refers to the length of one cycle of the twisted inner tubes 24. The "helix angle" is an angle defined as follows. When the inner tube assembly 26 is viewed in plan, a center line L_1 of the inner tube assembly 26, and a contact point P between the two inner tubes 24 at a position of an antinode of the inner tube assembly 26 are defined. Further, a tangent L_2 of the inner tubes 24 is defined so as to pass through the contact point P. The angle between the center line L_1 and the tangent L_2 is defined as the "helix angle".

[0031] As shown in FIG. 1, the first header 16 is composed of an outlet header 12 and an inlet header 14. The first header 16 serves the role of collecting the second fluid from the second flow passages 28h and introducing the first fluid into the first flow passages. The second header 22 is composed of an inlet header 18 and an outlet header 20. The second header 22 serves the role of introducing the second fluid into the second flow passages 28h and collecting the first fluid from the first flow passages 24h. When the second fluid flows through the second flow passages while the first fluid flows through the first flow passages, the heat is exchanged between the first fluid and the second fluid.

[0032] Examples of the first fluid include a refrigerant such as carbon dioxide, and examples of the second fluid include water. Carbon dioxide is suitable for heat pumps as a refrigerant with a low GWP (Global Warming Potential). Use of carbon dioxide as a refrigerant allows to heat the water to a temperature close to its boiling point. However, the two kinds of fluids to be subjected to heat exchange are not limited to these. Instead of water, oil, brine, etc. can be used as the second fluid. On the other hand, a fluorine refrigerant, such as hydrofluorocarbon, can also be used as the refrigerant.

[0033] Detailed structures of the first header 16 and the second header 22 are described in Patent Literature 1 (FIG. 6), for example.

[0034] In the present embodiment, the inner tubes 24 and the outer tube 28 each are composed of a copper tube. This makes it possible to exchange heat between the first fluid and the second fluid efficiently.

[0035] The second flow passage 28h may be formed with a member having a shape other than a tube shape. Such a member may be made of metal or may be made of a material other than metal. For example, the inner tubes 24 each may be made of a copper tube and the member (exterior body) corresponding to the outer tube 28 may be made of a resin. When the member (exterior body) corresponding to the outer tube 28 is made of a resin, it may be possible to provide a heat exchanger with a further reduced weight.

[0036] The member corresponding to the outer tube 28 may be made of, for example, a resin such as polyphenylene sulfide, polyetheretherketone, polytetrafluoroethylene, polysulfone, polyether sulfone, polyarylate, polyamide imide, polyether imide, a liquid crystal polymer, and polypropylene. These resins (thermoplastic resins) have excellent heat resistance and chemical durability and hardly deteriorate even when they are in contact with water. Also, the outer tube 28 may be made of a resin containing a reinforcing material such as a glass filler.

[0037] As shown in FIG. 2, the inner tubes 24 each are a leakage detection tube composed of a smooth-inner-surface tube 32 and an inner-surface-grooved tube 30 provided outside around the smooth-inner-surface tube 32. The smooth-inner-surface tube 32 has an outer diameter equal to an inner diameter of the inner-surface-grooved tube 30. The leakage detection tube makes it possible to prevent the first fluid from flowing into the second flow passage 28h even in the case where the smooth-inner-surface tube 32 is damaged. However, each inner tube 24 does not necessarily have to be a leakage detection tube. The inner tube 24 may be composed only of the smooth-inner-surface tube 32. Dimples (depressions and projections) may be formed on a surface of the inner tube 24. Such dimples increase the heat transfer coefficient on the surface of the inner tube 24.

[0038] As shown in FIG. 1, the path number N indicating the number of the heat exchange segments 10 disposed between the first header 16 and the second header 22 is 4 in the present embodiment. The path number N may be changed suitably in the range of 4 to 8 in accordance with the inner diameter of the outer tube 28 and the outer diameter of the inner tube 24.

[0039] As shown in FIG. 6 of Patent Literature 1 (JP 4414197 B), conventional double flow passage heat exchangers have a path number N of 2, for example. When the path number N is increased, the pressure loss decreases significantly because the flow passage area increases in proportion to the path number. However, the flow rate of the fluid decreases, and accordingly the heat transfer coefficient also decreases. In order to compensate the decrease in the heat exchanging capacity due to the decrease of the heat transfer coefficient, it is necessary to design appropriately the length of the flow passage per path. Even when the path number N is doubled, the length of the flow passage per path cannot be reduced by half. Thus, a mere increase in the path number fails to achieve the effect of reducing the weight of the double flow passage heat exchanger.

[0040] The present inventors investigated in detail the relationship among the number of the flow passages (path number), the inner diameter of the outer tube and the gap width through computer simulation. As a result, they found that when these parameters each take a specific value, it is possible to provide a heat exchanger having a reduced weight even while having a heat exchanging capacity equivalent to those of conventional double flow passage heat exchangers.

[0041] Specifically, the heat exchanger 100 of the present embodiment satisfies the following relationships. First, the path number N is in the range of 4 to 8. The inner diameter ϕ_{in} of the outer tube 28 is in the range of 6.52 to 9.50 mm. The gap width G represented by a difference $((\phi_{in} / 2) - \phi_{out})$ between a half of the inner diameter ϕ_{in} of the outer tube 28 and the outer diameter ϕ_{out} of the inner tube 24 satisfies $0 < G \leq 0.8$ (unit: mm). Further, the path number N and the inner diameter ϕ_{in} (unit: mm) of the outer tube 28 satisfy one of relationships (1) to (5) below. As can be understood from FIG. 2, an outer diameter of the inner tube assembly 26 is equal to twice the outer diameter ϕ_{out} of the inner tube 24.

$$(1) N = 4 \text{ and } 8.20 \leq \phi_{in} \leq 9.50$$

$$(2) N = 5 \text{ and } 7.58 \leq \phi_{in} \leq 8.90$$

$$(3) N = 6 \text{ and } 7.14 \leq \phi_{in} \leq 8.50$$

$$(4) N = 7 \text{ and } 6.78 \leq \phi_{in} \leq 8.20$$

$$(5) N = 8 \text{ and } 6.52 \leq \phi_{in} \leq 7.90$$

[0042] As the path number N increases, the number of soldering points increases and the structures of the headers 16 and 22 become more complex. A path number N exceeding 8 makes mass production difficult even if it accomplishes weight reduction. Moreover, an excessively large path number N makes it difficult for the first fluid and the second fluid to flow through each of the heat exchange segments 10 uniformly. Thus, it is desirable that the path number N is in the range of 4 to 8.

[0043] The gap width G of zero makes it impossible to put the inner tube assembly 26 into the outer tube 28. Thus, it is essential that the gap width G is larger than zero. Desirably, the gap width G is 0.16 mm or more. On the other hand, a gap width G exceeding 0.8 mm may lower the heat transfer coefficient on the surface of the inner tube 24 and deteriorate the heat exchanging performance notably. Thus, it is desirable that the gap width G has an upper limit of 0.8 mm.

[0044] Determinations of the inner diameter ϕ_{in} of the outer tube 28 and the gap width G determine the outer diameter ϕ_{out} of the inner tube 24. The weight reduction of the heat exchanger 100 can be achieved by reducing the inner diameter ϕ_{in} of the outer tube 28 and/or the outer diameter ϕ_{out} of the inner tube 24, and furthermore, by reducing the thickness of the outer tube 28 and/or the thickness of the inner tube 24. However, taking safety into consideration, the inner tube 24 and the outer tube 28 each need a certain thickness. Taking corrosion resistance into consideration, the detection tube 30 is adjusted to have a thickness (thickness of a portion without a groove) in the range of 0.5 to 0.7 mm, for example. From the same viewpoint, the outer tube 28 is adjusted to have a thickness in the range of 0.5 to 0.7 mm, for example. The smooth-inner-surface tube 32 is adjusted to have a thickness in the range of 0.2 to 0.4 mm, for example. The smooth-inner-surface tube 32 (refrigerant tube) is required to have a thickness capable of withstanding the pressure of the refrigerant (first fluid). An excessively large thickness of the smooth-inner-surface tube 32 affects the weight of the heat exchanger 100, costs, and the pressure loss of the refrigerant. Thus, the thickness of the smooth-inner-surface tube 32 can be determined in the range of, for example, 12 to 20% (desirably 12 to 16%) of the outer diameter of the smooth-inner-surface tube 32 itself.

[0045] The heat exchanging capacity of the heat exchanger 100 is not particularly limited. It is in the range of 4.5 to 6.0 kW, for example. The heat exchanger 100 having a heat exchanging capacity of such a magnitude can be used suitably for a home heat pump. Of course, in the case where a heat exchanging capacity larger than this is required, two units of the heat exchanger 100 can be used in parallel.

[0046] As shown in FIG. 1, the heat exchange segments 10 are unbent in the present embodiment. Each heat exchange segment 10 has a length of 2 to 5 meters, which depends on the path number N. Thus, in the heat exchanger 100 of the present embodiment, the heat exchange segment 10 may be bent in a scroll shape. Use of a slim tube for the heat exchange segment 10 may make it possible to decrease its bend radius and reduce a dead space.

[0047] Next, the applications of the heat exchanger 100 are described. FIG. 4 is a configuration diagram of a heat pump water heater 200 in which the heat exchanger 100 can be used.

[0048] The heat pump water heater 200 includes a heat pump unit 201 and a tank unit 203. The hot water made in the heat pump unit 201 is held in the tank unit 203. The hot water is supplied to a hot water tap 204 from the tank unit 203. The heat pump unit 201 includes a compressor 205 for compressing a refrigerant, a radiator 207 for cooling the refrigerant, an expansion mechanism 209 for expanding the refrigerant, an evaporator 211 for evaporating the refrigerant, and refrigerant tubes 213 connecting these devices in this order. Typically, the expansion mechanism 209 is an expansion valve. Instead of an expansion valve, a positive displacement expander capable of recovering the expansion energy of the refrigerant may be used. The heat exchanger 100 can be used as the radiator 207. The tank unit 203 includes a hot water storage tank 215 and a water circuit 217. The water circuit 217 serves the role of circulating water through the radiator 207.

EXAMPLES

[0049] The weight of the heat exchanger described with reference to FIGs. 1 to 3 was calculated through computer simulation, with the inner diameter ϕ_{in} of the outer tube being fixed at 7.06 mm or 8.6 mm and the path number N being changed variously. The gap width G was fixed at 0.4 mm. As a reference example, the calculation result of the heat exchanger with the path number N being 2 and the inner diameter ϕ_{in} of the outer tube being 10.8 mm was prepared. While the heat exchanging capacity was kept at the value of the reference example (about 4.7 kW), the path number N was changed. That is, the length of each heat exchange segment (the length of the outer tube) was set so that the same heat exchanging capacity as that of the reference example was achieved. The simulation conditions were as follows.

[0050] Software for analysis: REFPROP Version 7.0

Flow rate of water: 1.4 kg/minute

Temperature of water: 17°C

Kind of refrigerant: CO₂

Temperature of refrigerant (inlet): 87°C

Temperature of refrigerant (outlet): 20°C

Pressure of refrigerant: 9.6 MPa

Material of the outer tube and the inner tube: Copper

[0051] Table 1 and Table 2 show the results. Table 1 shows the results in the case where $\phi_{in} = 7.06$ mm. Table 2 shows the results in the case where $\phi_{in} = 8.6$ mm.

[Table 1]

			$\phi 7.06 \times$ 8 paths	$\phi 7.06 \times$ 12 paths	$\phi 7.06 \times$ 16 paths	$\phi 7.06 \times$ 24 paths	$\phi 7.06 \times$ 36 paths	$\phi 10.8 \times$ 2 paths
Outer tube (Water)	Outer diameter	[mm]	8.26	8.26	8.26	8.26	8.26	12.00
	Thickness	[mm]	0.60	0.60	0.60	0.60	0.60	0.60
	Inner diameter	[mm]	7.06	7.06	7.06	7.06	7.06	10.80
	Gap	[mm]	0.40	0.40	0.40	0.40	0.40	0.40
	Path number	[-]	8	12	16	24	36	2
	Tube length	[m]	2.85	2.39	2.16	1.92	1.75	7.92
Water-side cross-sectional area			181.55 (1.000)	272.33 (1.500)	363.11 (2.000)	544.66 (3.000)	817.00 (4.500)	102.42

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(continued)

			$\phi 7.06 \times 8$ paths	$\phi 7.06 \times 12$ paths	$\phi 7.06 \times 16$ paths	$\phi 7.06 \times 24$ paths	$\phi 7.06 \times 36$ paths	$\phi 10.8 \times 2$ paths
5		Water-side heat transfer coefficient [W/(m ² ·K)]	5198 (1.000)	4377 (0.842)	3875 (0.745)	3263 (0.628)	2747 (0.529)	4236
10		Water-side pressure bss [kPa]	4.53 (1.000)	2.23 (0.492)	1.38 (0.305)	0.72 (0.159)	0.39 (0.085)	10.48
		Weight of outer tube [kg]	2.92 (1.000)	3.68 (1.258)	4.43 (1.516)	5.91 (2.021)	8.08 (2.763)	3.02
15	Inner tube (CO ₂)	Outer diameter of detection tube [mm]	3.13	3.13	3.13	3.13	3.13	5.00
		Thickness of detection tube [mm]	0.68	0.68	0.68	0.68	0.68	0.68
20		Outer diameter of CO ₂ tube [mm]	1.77	1.77	1.77	1.77	1.77	3.64
		Thickness of CO ₂ tube [mm]	0.22	0.22	0.22	0.22	0.22	0.45
		Inner diameter of CO ₂ tube [mm]	1.33	1.33	1.33	1.33	1.33	2.74
25		CO ₂ -side heat transfer coefficient [W/(m ² ·K)]	8179 (1.000)	5698 (0.697)	4425 (0.541)	3086 (0.377)	2120 (0.259)	7024
30		CO ₂ -side pressure bss [kPa]	162.43 (1.000)	66.63 (0.410)	36.34 (0.224)	15.92 (0.098)	7.18 (0.044)	163.56
		Weight of detection tube [kg]	2.27 (1.000)	2.85 (1.258)	3.43 (1.516)	4.58 (2.021)	6.26 (2.763)	2.67
35		Weight of CO ₂ tube [kg]	0.46 (1.000)	0.58 (1.258)	0.70 (1.516)	0.93 (2.021)	1.28 (2.763)	1.31
	Heat exchanger	Amount of heat exchange [W]	4721 (1.000)	4726 (1.001)	4725 (1.001)	4725 (1.001)	4724 (1.001)	4738
40		Total weight [kg]	5.65 (1.000)	7.11 (1.258)	8.57 (1.516)	11.42 (2.021)	15.61 (2.763)	7.00

[Table 2]

		ϕ 8.6 x 4 paths	ϕ 8.6 x 6 paths	ϕ 8.6 x 8 paths	ϕ 8.6 x 12 paths	ϕ 8.6 x 16 paths	ϕ 8.6 x 24 paths	ϕ 8.6 x 36 paths	ϕ 10.8 x 2 paths
Outer tube (Water)	Outer diameter [mm]	9.80	9.80	9.80	9.80	9.80	9.80	9.80	12.00
	Thickness [mm]	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
	Inner diameter [mm]	8.60	8.60	8.60	8.60	8.60	8.60	8.60	10.80
	Gap [mm]	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	Path number [-]	4	6	8	12	16	24	36	2
	Tube length [m]	4.72	3.87	3.48	3.06	2.83	2.58	2.44	7.92
Inner tube (CO ₂)	Water-side cross-sectional area [mm ²]	132.40 (1.000)	198.60 (1.500)	264.80 (2.000)	397.21 (3.000)	529.61 (4.000)	794.41 (6.000)	1191.62 (9.000)	102.42
	Water-side heat transfer coefficient [W/(m ² ·K)]	4816 (1.000)	4056 (0.842)	3590 (0.745)	3024 (0.628)	2677 (0.556)	2254 (0.468)	1897 (0.394)	4236
	Water-side pressure bss [kPa]	7.32 (1.000)	3.53 (0.482)	2.17 (0.297)	1.12 (0.153)	0.71 (0.097)	0.38 (0.052)	0.21 (0.029)	10.48
	Weight of outer tube [kg]	2.91 (1.000)	3.58 (1.230)	4.29 (1.475)	5.65 (1.945)	6.97 (2.398)	9.54 (3.280)	13.53 (4.653)	3.02
	Outer diameter of detection tube [mm]	3.90	3.90	3.90	3.90	3.90	3.90	3.90	5.00
	Thickness of detection tube [mm]	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
	Outer diameter of CO ₂ tube [mm]	2.54	2.54	2.54	2.54	2.54	2.54	2.54	3.64
	Thickness of CO ₂ tube [mm]	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.45
	Inner diameter of CO ₂ tube [mm]	1.91	1.91	1.91	1.91	1.91	1.91	1.91	2.74
	CO ₂ -side heat transfer coefficient [W/(m ² ·K)]	7566 (1.000)	5265 (0.696)	4101 (0.542)	2881 (0.381)	2234 (0.295)	1540 (0.203)	1028 (0.136)	7024
	CO ₂ -side pressure bss [kPa]	160.75 (1.000)	63.95 (0.398)	34.63 (0.215)	14.96 (0.093)	8.38 (0.052)	3.78 (0.024)	1.77 (0.011)	163.56
	Weight of detection tube [kg]	2.41 (1.000)	2.97 (1.230)	3.56 (1.475)	4.69 (1.945)	5.79 (2.398)	7.91 (3.280)	11.22 (4.653)	2.67

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(continued)

		ϕ 8.6 x 4 paths	ϕ 8.6 x 6 paths	ϕ 8.6 x 8 paths	ϕ 8.6 x 12 paths	ϕ 8.6 x 16 paths	ϕ 8.6 x 24 paths	ϕ 8.6 x 36 paths	ϕ 10.8 x 2 paths
	Weight of CO ₂ tube [kg]	0.77 (1.000)	0.95	1.14	1.50	1.85	2.53	3.58	1.31
Heat exchanger	Amount of heat exchange [W]	4729 (1.000)	4724 (0.999)	4724 (0.999)	4724 (0.999)	4724 (0.999)	4724 (0.999)	4725 (0.999)	4738
	Total weight [kg]	6.09 (1.000)	7.49 (1.230)	8.98 (1.475)	11.84 (1.945)	14.61 (2.398)	19.97 (3.280)	28.33 (4.653)	7.00

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[0052] As shown in the item of total weight in Table 1, when $\phi_{in} = 7.06$ mm, the heat exchanger was lighter than the reference example only in the case where the heat exchanger had eight paths. As shown in the item of total weight in Table 2, when $\phi_{in} = 8.6$ mm, the heat exchanger was lighter than the reference example only in the case where the heat exchanger had four paths.

5 **[0053]** Next, various combinations of the inner diameter ϕ_{in} of the outer tube and the path number N were investigated with the gap width G being fixed at 0.4 mm. Then combinations of the inner diameter ϕ_{in} of the outer tube and the path number N that made the heat exchanger lighter than the reference example were picked out. Table 3 shows the results.

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[Table 3]

	ϕ 10.8 x 2 paths	ϕ 9.4 x 3 paths	ϕ 8.6 x 4 paths	ϕ 8.0 x 5 paths	ϕ 7.58 x 6 paths	ϕ 7.28 x 7 paths	ϕ 7.02 x 8 paths	ϕ 6.82 x 9 paths	ϕ 6.64 x 10 paths	ϕ 6.5 x 11 paths	ϕ 6.37 x 12 paths	ϕ 6.0 x 16 paths	ϕ 5.54 x 24 paths	ϕ 5.17 x 36 paths
Outer tube (Water)	Outer diameter [mm]	12.00	10.60	9.80	9.20	8.78	8.48	8.22	8.02	7.84	7.70	7.57	7.20	6.37
	Thickness [mm]	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
	Inner diameter [mm]	10.80	9.40	8.60	8.00	7.58	7.28	7.02	6.82	6.64	6.50	6.37	6.00	5.17
	Gap [mm]	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	Path number [-]	2	3	4	5	6	7	8	9	10	11	12	16	36
	Tube length [m]	7.92	5.78	4.72	3.92	3.33	2.95	2.62	2.37	2.26	2.13	2.02	1.75	1.01
	Water-side cross-sectional area [mm ²]	102.42 (1.000)	117.94 (1.152)	132.40 (1.293)	143.37 (1.400)	153.71 (1.501)	165.15 (1.613)	174.37 (1.703)	184.09 (1.797)	195.96 (1.913)	207.36 (2.025)	218.00 (2.129)	263.90 (2.577)	444.72 (4.342)
	Water-side heat transfer coefficient [W/(m ² ·K)]	4236 (1.000)	4543 (1.072)	4816 (1.137)	5177 (1.222)	5543 (1.309)	5703 (1.346)	5958 (1.407)	6126 (1.446)	5977 (1.411)	5920 (1.397)	5882 (1.388)	5446 (1.286)	5175 (1.222)
	Water-side pressure loss [kPa]	10.48 (1.000)	8.42 (0.803)	7.32 (0.698)	6.76 (0.645)	6.38 (0.608)	5.82 (0.555)	5.54 (0.529)	5.21 (0.497)	4.60 (0.439)	4.16 (0.396)	3.80 (0.363)	2.60 (0.248)	1.08 (0.103)
	Weight of outer tube [kg]	3.02 (1.000)	2.90 (0.960)	2.91 (0.962)	2.82 (0.933)	2.74 (0.905)	2.72 (0.901)	2.67 (0.884)	2.65 (0.876)	2.74 (0.906)	2.78 (0.921)	2.82 (0.933)	3.09 (1.023)	3.51 (1.162)
Inner tube (CO ₂)	Outer diameter of detection tube [mm]	5.00	4.30	3.90	3.60	3.39	3.24	3.11	3.01	2.92	2.85	2.79	2.60	2.19
	Thickness of detection tube [mm]	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
	Outer diameter of CO ₂ tube [mm]	3.64	2.94	2.54	2.24	2.03	1.88	1.75	1.65	1.56	1.49	1.43	1.24	1.01
	Thickness of CO ₂ tube [mm]	0.45	0.36	0.31	0.28	0.25	0.23	0.22	0.20	0.19	0.18	0.18	0.15	0.10
	Inner diameter of CO ₂ tube [mm]	2.74	2.21	1.91	1.69	1.53	1.42	1.32	1.24	1.17	1.12	1.07	0.93	0.62
	CO ₂ -side heat transfer coefficient [W/(m ² ·K)]	7024 (1.000)	7358 (1.048)	7566 (1.077)	7898 (1.124)	8109 (1.154)	8193 (1.167)	8349 (1.189)	8416 (1.198)	8553 (1.218)	8585 (1.222)	8660 (1.233)	8782 (1.250)	9327 (1.328)

(continued)

	ϕ 10.8 x 2 paths	ϕ 9.4 x 3 paths	ϕ 8.6 x 4 paths	ϕ 8.0 x 5 paths	ϕ 7.58 x 6 paths	ϕ 7.28 x 7 paths	ϕ 7.02 x 8 paths	ϕ 6.82 x 9 paths	ϕ 6.64 x 10 paths	ϕ 6.5 x 11 paths	ϕ 6.37 x 12 paths	ϕ 6.0 x 16 paths	ϕ 5.54 x 24 paths	ϕ 5.17 x 36 paths
	163.56 (1.000)	160.95 (0.984)	160.75 (0.983)	166.07 (1.015)	166.52 (1.018)	163.96 (1.002)	164.79 (1.008)	162.72 (0.995)	167.36 (1.023)	166.00 (1.015)	166.75 (1.020)	166.90 (1.020)	167.27 (1.023)	167.39 (1.023)
	2.67 (1.000)	2.47 (0.924)	2.41 (0.903)	2.30 (0.862)	2.22 (0.831)	2.19 (0.821)	2.15 (0.805)	2.13 (0.797)	2.16 (0.807)	2.17 (0.811)	2.17 (0.813)	2.26 (0.847)	2.30 (0.861)	2.39 (0.896)
	1.31 (1.000)	0.94 (0.719)	0.77 (0.590)	0.63 (0.483)	0.54 (0.412)	0.48 (0.370)	0.43 (0.331)	0.40 (0.304)	0.37 (0.286)	0.35 (0.271)	0.33 (0.256)	0.29 (0.221)	0.22 (0.170)	0.17 (0.132)
Heat exchanger	4738 (1.000)	4723 (0.997)	4729 (0.998)	4727 (0.998)	4726 (0.997)	4726 (0.997)	4726 (0.997)	4726 (0.997)	4728 (0.998)	4727 (0.998)	4727 (0.998)	4727 (0.998)	4726 (0.997)	4726 (0.997)
	7.00 (1.000)	6.31 (0.901)	6.09 (0.870)	5.75 (0.822)	5.49 (0.785)	5.40 (0.771)	5.26 (0.751)	5.18 (0.740)	5.27 (0.753)	5.30 (0.758)	5.33 (0.761)	5.64 (0.807)	5.78 (0.826)	6.08 (0.868)

[0054] The graphs of FIG. 5 and FIG. 6 show the results in Table 3. In the graph of FIG. 5, the horizontal axis indicates the path number N and the vertical axis indicates weight. In FIG. 5, the leftmost marks correspond to the results of the reference example. In the graph of FIG. 6, the horizontal axis indicates the inner diameter ϕ_{in} of the outer tube and the vertical axis indicates the path number N. As shown in FIG. 6, in order to reduce the weight while keeping the heat exchanging capacity equivalent to that of the reference example, it is necessary to choose appropriately the inner diameter ϕ_{in} of the outer tube in accordance with the path number N.

[0055] As shown in Table 3 and FIG. 5, when the gap width G was 0.4 mm, the heat exchanger had a minimum weight under the conditions that $\phi_{in} = 6.82$ mm and it had nine paths. However, a path number N exceeding 8 may lower the productivity.

[0056] Next, various combinations of the inner diameter ϕ_{in} of the outer tube and the path number N were investigated under each condition that (a) the gap width G was 0.8 mm, (b) the gap width G was 0 mm, and (c) the gap width G was optimized. Table 4 shows the results in the case of (a). Table 5 shows the results in the case of (b). Table 6 shows the results in the case of (c). Further, FIG. 7 shows the results in Tables 3 to 6.

[Table 4]

			$\phi 9.5 \times 4$ paths	$\phi 8.9 \times 5$ paths	$\phi 8.5 \times 6$ paths	$\phi 8.2 \times 7$ paths	$\phi 7.9 \times 8$ paths	$\phi 10.8$ $\times 2$ paths
Outer tube (Water)	Outer diameter [mm]		10.70	10.10	9.70	9.40	9.10	12.00
	Thickness [mm]		0.60	0.60	0.60	0.60	0.60	0.60
	Inner diameter [mm]		9.50	8.90	8.50	8.20	7.90	10.80
	Gap [mm]		0.80	0.80	0.80	0.80	0.80	0.40
	Path number [-]		4	5	6	7	8	2
	Tube length [m]		5.08	4.24	3.60	3.19	2.84	7.92
	Water-side cross-sectional area [mm ²]		180.89 (1.000)	199.91 (1.105)	218.93 (1.210)	238.33 (1.318)	253.01 (1.399)	102.42
	Water-side heat transfer coefficient [W/(m ² ·K)]		4059 (1.000)	4315 (1.063)	4568 (1.125)	4667 (1.150)	4858 (1.197)	4236
	Water-side pressure loss [kPa]		3.71 (1.000)	3.29 (0.884)	2.96 (0.796)	2.62 (0.704)	2.44 (0.658)	10.48
	Weight of outer tube [kg]		3.44 (1.000)	3.37 (0.981)	3.29 (0.958)	3.29 (0.957)	3.23 (0.941)	3.02
Inner tube (CO ₂)	Outer diameter of detection tube [mm]		3.95	3.65	3.45	3.30	3.15	5.00
	Thickness of detection tube [mm]		0.68	0.68	0.68	0.68	0.68	0.68
	Outer diameter of CO ₂ tube [mm]		2.59	2.29	2.09	1.94	1.79	3.64
	Thickness of CO ₂ tube [mm]		0.32	0.28	0.26	0.24	0.22	0.45
	Inner diameter of CO ₂ tube [mm]		1.95	1.72	1.57	1.46	1.35	2.74
	CO ₂ -side heat transfer coefficient [W/(m ² ·K)]		7315 (1.000)	7603 (1.039)	7697 (1.052)	7742 (1.058)	8031 (1.098)	7024
	CO ₂ -side pressure loss [kPa]		157.44 (1.000)	161.68 (1.027)	156.80 (0.996)	152.79 (0.970)	160.52 (1.020)	163.56
	Weight of detection tube [kg]		2.64 (1.000)	2.54 (0.961)	2.46 (0.932)	2.43 (0.922)	2.38 (0.900)	2.67

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(continued)

		ϕ 9.5 x4 paths	ϕ 8.9 x5 paths	ϕ 8.5 x6 paths	ϕ 8.2 x7 paths	ϕ 7.9 x8 paths		ϕ 10.8 x2 paths
	Weight of CO ₂ tube [kg]	0.86 (1.000)	0.71 (0.827)	0.62 (0.716)	0.56 (0.646)	0.49 (0.569)		1.31
Heat exchanger	Amount of heat exchange [W]	4729 (1.000)	4729 (1.000)	4728 (1.000)	4727 (1.000)	4728 (1.000)		4738
	Total weight [kg]	6.94 (1.000)	6.62 (0.955)	6.37 (0.918)	6.28 (0.905)	6.10 (0.879)		7.00

[Table 5]

		ϕ 9.2 x4 paths	ϕ 8.6 x5 paths	ϕ 8.2 x6 paths	ϕ 7.9 x7 paths	ϕ 7.7 x8 paths		ϕ 10.8 x2 paths
Outer tube (Water)	Outer diameter [mm]	10.40	9.80	9.40	9.10	8.90		12.00
	Thickness [mm]	0.60	0.60	0.60	0.60	0.60		0.60
	Inner diameter [mm]	9.20	8.60	8.20	7.90	7.70		10.80
	Gap [mm]	0.00	0.00	0.00	0.00	0.00		0.40
	Path number [-]	4	5	6	7	8		2
	Tube length [m]	4.56	3.82	3.27	2.92	2.61		7.92
	Water-side cross-sectional area [mm ²]	124.54 (1.000)	132.81 (1.066)	140.05 (1.125)	148.18 (1.190)	154.85 (1.243)		102.42
	Water-side heat transfer coefficient [W/(m ² ·K)]	5085 (1.000)	5524 (1.086)	5985 (1.177)	6222 (1.224)	6558 (1.290)		4236
	Water-side pressure loss [kPa]	10.36 (1.000)	10.29 (0.994)	10.50 (1.014)	10.22 (0.987)	10.40 (1.004)		10.48
	Weight of outer tube [kg]	2.99 (1.000)	2.94 (0.983)	2.89 (0.966)	2.91 (0.972)	2.90 (0.970)		3.02
Inner tube (CO ₂)	Outer diameter of detection tube [mm]	4.60	4.30	4.10	3.95	3.85		5.00
	Thickness of detection tube [mm]	0.68	0.68	0.68	0.68	0.68		0.68
	Outer diameter of CO ₂ tube [mm]	3.24	2.94	2.74	2.59	2.49		3.64
	Thickness of CO ₂ tube [mm]	0.40	0.36	0.34	0.32	0.31		0.45
	Inner diameter of CO ₂ tube [mm]	2.44	2.21	2.06	1.95	1.87		2.74
	CO ₂ -side heat transfer coefficient [W/(m ² ·K)]	4702 (1.000)	4650 (0.989)	4528 (0.963)	4403 (0.936)	4219 (0.897)		7024
	CO ₂ -side pressure loss [kPa]	49.39 (1.000)	45.30 (0.917)	40.45 (0.819)	36.67 (0.742)	32.15 (0.651)		163.56
	Weight of detection tube [kg]	2.88 (1.000)	2.85 (0.987)	2.84 (0.985)	2.88 (0.999)	2.93 (1.017)		2.67

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(continued)

		$\phi 9.2 \times 4$ paths	$\phi 8.6 \times 5$ paths	$\phi 8.2 \times 6$ paths	$\phi 7.9 \times 7$ paths	$\phi 7.7 \times 8$ paths		$\phi 10.8$ $\times 2$ paths
	Weight of CO ₂ tube [kg]	1.23 (1.000)	1.08 (0.880)	0.99 (0.807)	0.94 (0.765)	0.91 (0.743)		1.31
Heat exchanger	Amount of heat exchange [W]	4729 (1.000)	4729 (1.000)	4729 (1.000)	4729 (1.000)	4728 (1.000)		4738
	Total weight [kg]	7.11 (1.000)	6.87 (0.967)	6.72 (0.946)	6.73 (0.947)	6.75 (0.950)		7.00

[Table 6]

		$\phi 8.2 \times 4$ paths	$\phi 7.58$ $\times 5$ paths	$\phi 7.14$ $\times 6$ paths	$\phi 6.78$ $\times 7$ paths	$\phi 6.52$ $\times 8$ paths		$\phi 10.8$ $\times 2$ paths
Outer tube (Water)	Outer diameter [mm]	9.40	8.78	8.34	7.98	7.72		12.00
	Thickness [mm]	0.60	0.60	0.60	0.60	0.60		0.60
	Inner diameter [mm]	8.20	7.58	7.14	6.78	6.52		10.80
	Gap [mm]	0.22	0.20	0.19	0.17	0.16		0.40
	Path number [-]	4	5	6	7	8		2
	Tube length [m]	4.54	3.76	3.19	2.81	2.49		7.92
	Water-side cross-sectional area [mm ²]	112.36 (1.000)	118.30 (1.053)	123.93 (1.103)	128.18 (1.141)	132.78 (1.182)		102.42
	Water-side heat transfer coefficient [W/(m ² ·K)]	5273 (1.000)	5758 (1.092)	6246 (1.185)	6562 (1.244)	6932 (1.315)		4236
	Water-side pressure loss [kPa]	10.51 (1.000)	10.41 (0.991)	10.40 (0.990)	10.33 (0.983)	10.34 (0.984)		10.48
	Weight of outer tube [kg]	2.67 (1.000)	2.57 (0.962)	2.48 (0.927)	2.43 (0.908)	2.37 (0.888)		3.02
Inner tube (CO ₂)	Outer diameter of detection tube [mm]	3.88	3.59	3.38	3.22	3.10		5.00
	Thickness of detection tube [mm]	0.68	0.68	0.68	0.68	0.68		0.68
	Outer diameter of CO ₂ tube [mm]	2.52	2.23	2.02	1.86	1.74		3.64
	Thickness of CO ₂ tube [mm]	0.31	0.28	0.25	0.23	0.22		0.45
	Inner diameter of CO ₂ tube [mm]	1.90	1.68	1.52	1.40	1.31		2.74
	CO ₂ -side heat transfer coefficient [W/(m ² ·K)]	7663 (1.000)	7946 (1.037)	8166 (1.066)	8342 (1.089)	8415 (1.098)		7024
	CO ₂ -side pressure loss [kPa]	160.62 (1.000)	162.98 (1.015)	163.64 (1.019)	164.58 (1.025)	161.30 (1.004)		163.56
	Weight of detection tube [kg]	2.30 (1.000)	2.20 (0.955)	2.12 (0.919)	2.07 (0.898)	2.03 (0.883)		2.67

(continued)

		ϕ 8.2 x4 paths	ϕ 7.58 x5 paths	ϕ 7.14 x6 paths	ϕ 6.78 x7 paths	ϕ 6.52 x8 paths	ϕ 10.8 x2 paths
	Weight of CO ₂ tube [kg]	0.73 (1.000)	0.60 (0.822)	0.51 (0.700)	0.45 (0.617)	0.41 (0.556)	1.31
Heat exchanger	Amount of heat exchange [W]	4729 (1.000)	4728 (1.000)	4728 (1.000)	4728 (1.000)	4728 (1.000)	4738
	Total weight [kg]	5.71 (1.000)	5.37 (0.941)	5.11 (0.895)	4.95 (0.867)	4.81 (0.843)	7.00

[0057] A gap width G exceeding 0.8 mm may lower the heat transfer coefficient on the surface of the inner tube and deteriorate the heat exchanging performance notably. Thus, no simulation was conducted in a range exceeding 0.8 mm. On the other hand, the lower limit of the gap width G is not particularly limited. As shown in Table 6, however, the optimization of the gap width G can reduce the weight of the heat exchanger maximally compared to the case of the reference example.

[0058] That is, the data obtained when the gap width G was optimized in a range in which the pressure loss of the second fluid (water) did not exceed a certain value indicates the gap width G that can minimize the weight of the heat exchanger. Thus, the data obtained when the gap width G was optimized can be regarded as a suitable lower limit. Moreover, in Table 6, the lowest value of the gap width G is 0.16 mm, and the path number N at that time is 8.

[0059] As can be understood from the data obtained when the gap width G was 0 mm, when the gap width G comes closer to 0 mm, it becomes necessary to suppress the pressure loss of the water, making it necessary to increase the inner diameter ϕ_{in} of the outer tube. As a result, the inner diameter ϕ_{in} of the outer tube when the gap width G is 0 mm is larger than the inner diameter ϕ_{in} of the outer tube when the gap width G is 0.4 mm.

[0060] As shown in FIG. 7, in the case where $8.20 \leq \phi_{in} \leq 9.50$ is satisfied when $N = 4$, it is possible to reduce the weight of the double flow passage heat exchanger while keeping the heat exchanging capacity equivalent to that of the reference example. Similarly, it is possible to reduce the weight of the double flow passage heat exchanger by satisfying $7.58 \leq \phi_{in} \leq 8.90$ when $N = 5$, $7.14 \leq \phi_{in} \leq 8.50$ when $N = 6$, $6.78 \leq \phi_{in} \leq 8.20$ when $N = 7$, and $6.52 \leq \phi_{in} \leq 7.90$ when $N = 8$.

[0061] In this simulation, the detection tube and the inner tube are regarded as one integrated tube, the presence of the detection tube does not affect the results of the simulation. The detection tube has a fixed thickness of 0.68 mm. In the case where no detection tube is used, it is necessary to increase the thickness of the smooth-inner-surface tube in order to enhance the corrosion resistance.

[0062] Next, the material of the outer tube was changed to polyphenylene sulfide (PPS) containing a glass filler at a ratio of 30 wt%, and the same simulation as the one yielded the results of Table 3 was conducted. Table 7 and FIG. 8 show the results. As in Table 3 and FIG. 5, the leftmost column in Table 7 and the leftmost marks in FIG. 8 correspond to the results of the reference example.

[Table 7]

			$\phi 10.8$ x 2 paths	$\phi 9.4$ x 3 paths	$\phi 8.6$ x 4 paths	$\phi 8.0$ x 5 paths	$\phi 7.58$ x 6 paths	$\phi 7.28$ x 7 paths	$\phi 7.02$ x 8 paths	$\phi 6.82$ x 9 paths	$\phi 6.64$ x 10 paths	$\phi 6.5$ x 11 paths	$\phi 6.37$ x 12 paths	$\phi 6.0$ x 16 paths	$\phi 5.54$ x 24 paths	$\phi 5.17$ x 36 paths
	Thickness	[mm]	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
	Weight of outer tube	[kg]	0.84	0.81	0.82	0.80	0.77	0.77	0.76	0.75	0.78	0.79	0.80	0.88	0.93	1.01
	Total weight	[kg]	4.82	4.22	4.00	3.73	3.53	3.44	3.34	3.28	3.31	3.31	3.30	3.43	3.45	3.57
Outer tube (Water)																
Heat exchanger																

[0063] As shown in Table 7 and FIG. 8, even with the outer tube made of a resin, the heat exchanger had a minimum weight under the conditions that $\phi_{in} = 6.82$ mm and it had nine paths as in the case where the outer tube made of copper was used. The graph of FIG. 8 exhibited the same tendency as that of the graph of FIG. 5. This indicates that the conclusion (see FIG. 7) obtained from the heat exchanger including the outer tube made of copper holds true for the heat exchanger including the outer tube made of a resin.

INDUSTRIAL APPLICABILITY

[0064] The heat exchanger of the present invention can be used for apparatuses such as a heat pump type water heater and a hot water heating system.

Claims

1. A heat exchanger for exchanging heat between a first fluid and a second fluid, comprising:

a plurality of heat exchange segments each having a first flow passage and a second flow passage;
 a first header provided at one end of the heat exchange segments so that the first fluid is introduced into the first flow passage and the second fluid is collected from the second flow passage; and
 a second header provided at another end of the heat exchange segments so that the first fluid is collected from the first flow passage and the second fluid is introduced into the second flow passage,
 wherein each of the heat exchange segments is composed of (i) an inner tube assembly that includes two inner tubes each having the first flow passage and that is formed of the two inner tubes twisted spirally, and (ii) an exterior body accommodating the inner tube assembly so that the second flow passage is formed between an inner circumferential surface of the exterior body and an outer circumferential surface of the inner tube assembly,
 a path number N indicating the number of the heat exchange segments disposed between the first header and the second header is 4 to 8,
 a gap width G represented by a difference $((\phi_{in} / 2) - \phi_{out})$ between a half of an inner diameter ϕ_{in} of the exterior body and an outer diameter ϕ_{out} of the inner tube satisfies $0 < G \leq 0.8$ (unit: mm), and
 the path number N and the inner diameter ϕ_{in} (unit: mm) of the exterior body satisfy one of relationships (1) to (5) below.

$$(1) N = 4 \text{ and } 8.20 \leq \phi_{in} \leq 9.50$$

$$(2) N = 5 \text{ and } 7.58 \leq \phi_{in} \leq 8.90$$

$$(3) N = 6 \text{ and } 7.14 \leq \phi_{in} \leq 8.50$$

$$(4) N = 7 \text{ and } 6.78 \leq \phi_{in} \leq 8.20$$

$$(5) N = 8 \text{ and } 6.52 \leq \phi_{in} \leq 7.90$$

2. The heat exchanger according to claim 1, wherein the gap width G satisfies $0.16 \leq G \leq 0.8$.

3. The heat exchanger according to claim 1, wherein the inner tubes and the exterior body each are composed of a copper tube.

4. The heat exchanger according to claim 1, wherein the inner tubes each are composed of a copper tube and the exterior body is made of a resin.

5. The heat exchanger according to claim 1, wherein the inner tubes each are a leakage detection tube composed of a smooth-inner-surface tube and an inner-surface-grooved tube provided outside around the smooth-inner-surface

tube.

6. The heat exchanger according to claim 1, wherein the first fluid is carbon dioxide and the second fluid is water.

5 7. A heat pump comprising:

a compressor for compressing a refrigerant;

a radiator for cooling the compressed refrigerant, the radiator being composed of the heat exchanger according to claim 1;

10 an expansion mechanism for expanding the cooled refrigerant;

an evaporator for evaporating the expanded refrigerant; and

a water circuit for circulating water through the radiator.

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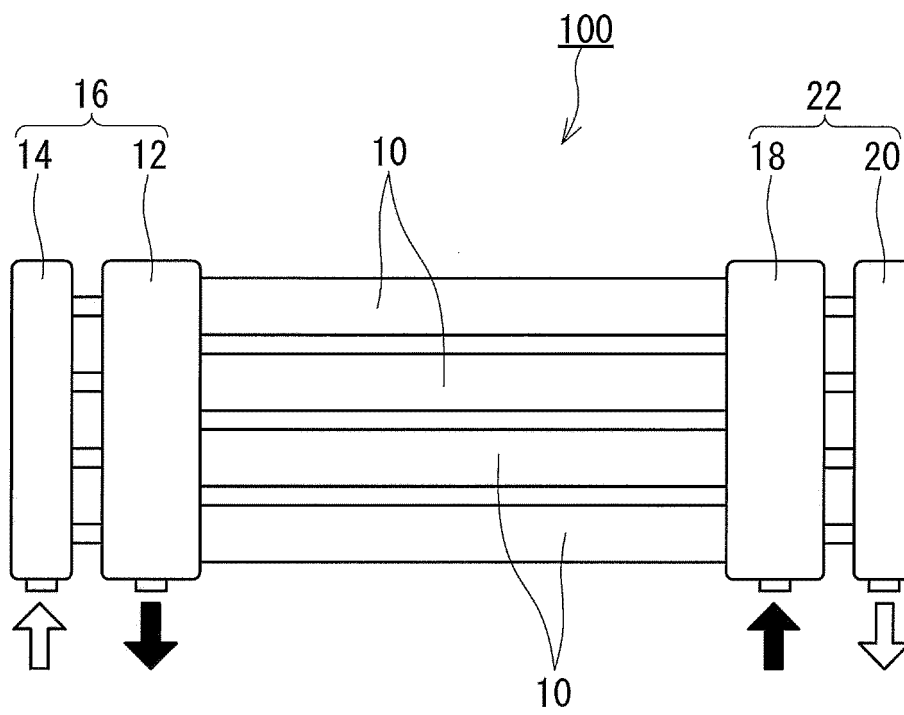


FIG.1

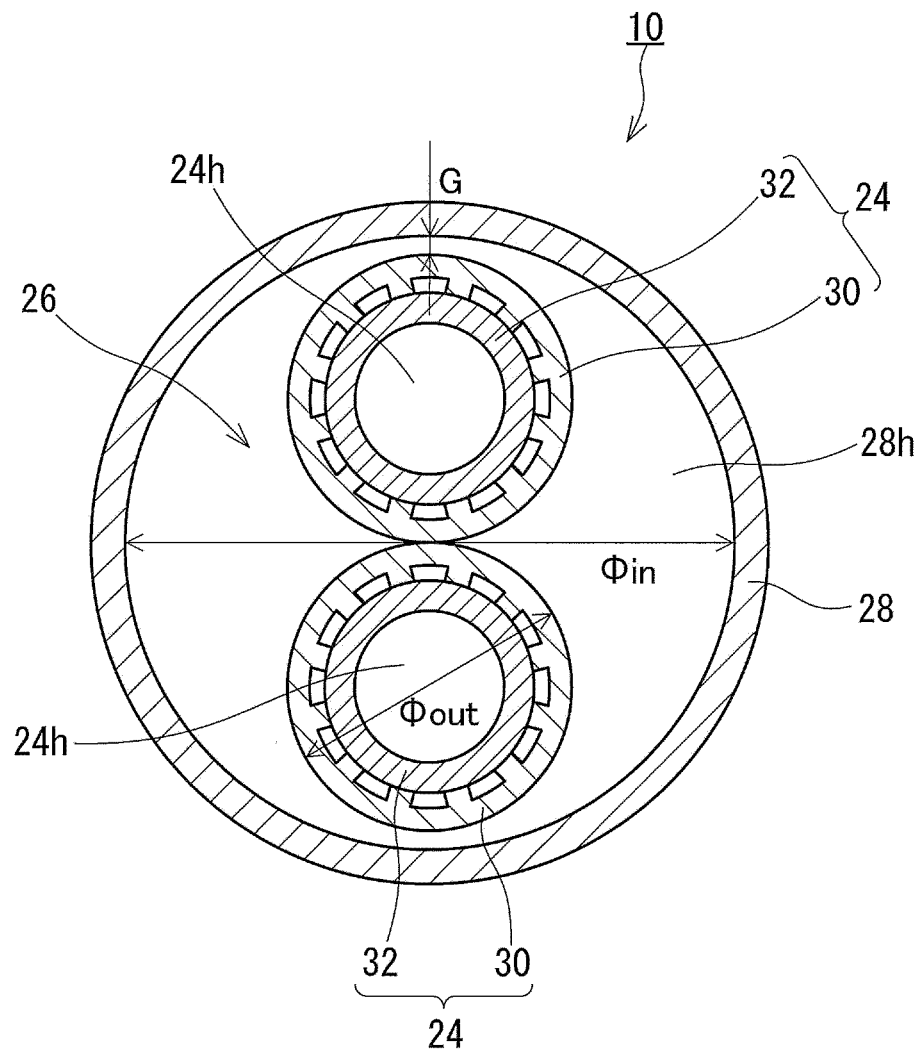


FIG.2

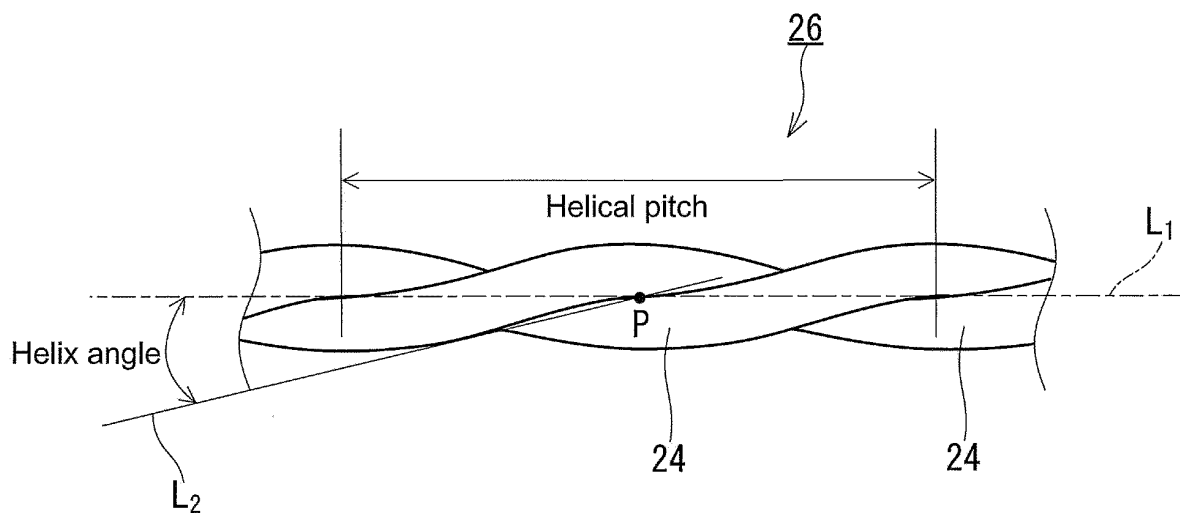


FIG. 3

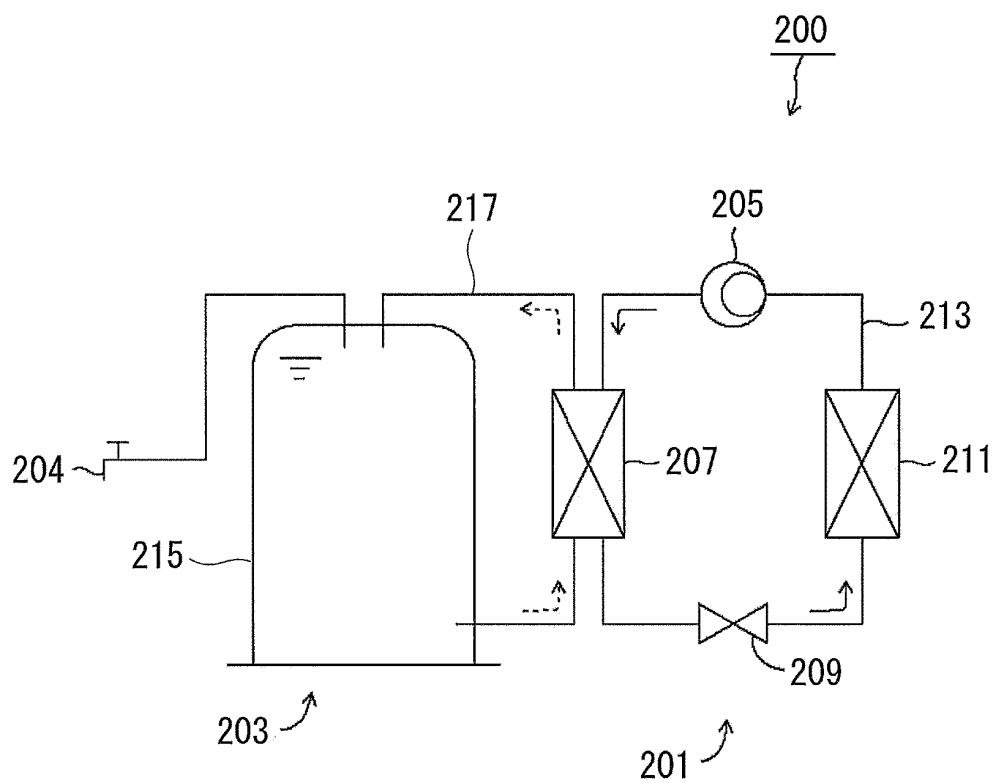


FIG. 4

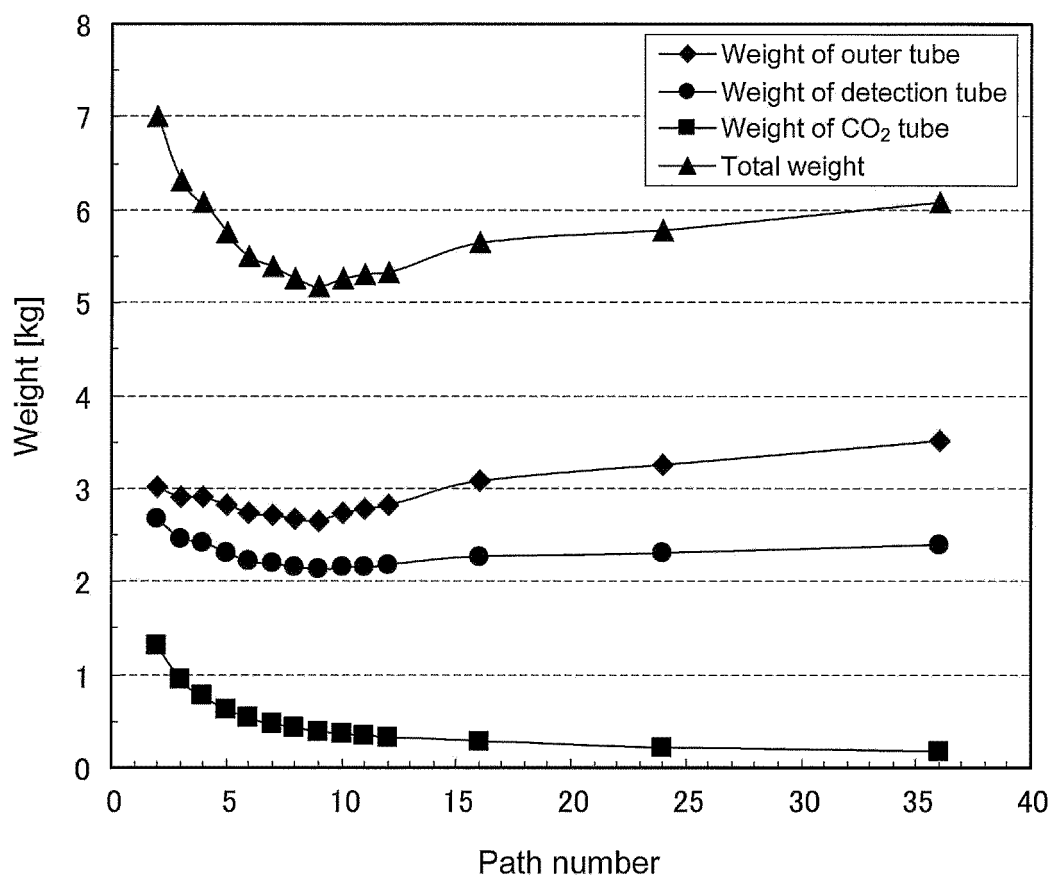


FIG.5

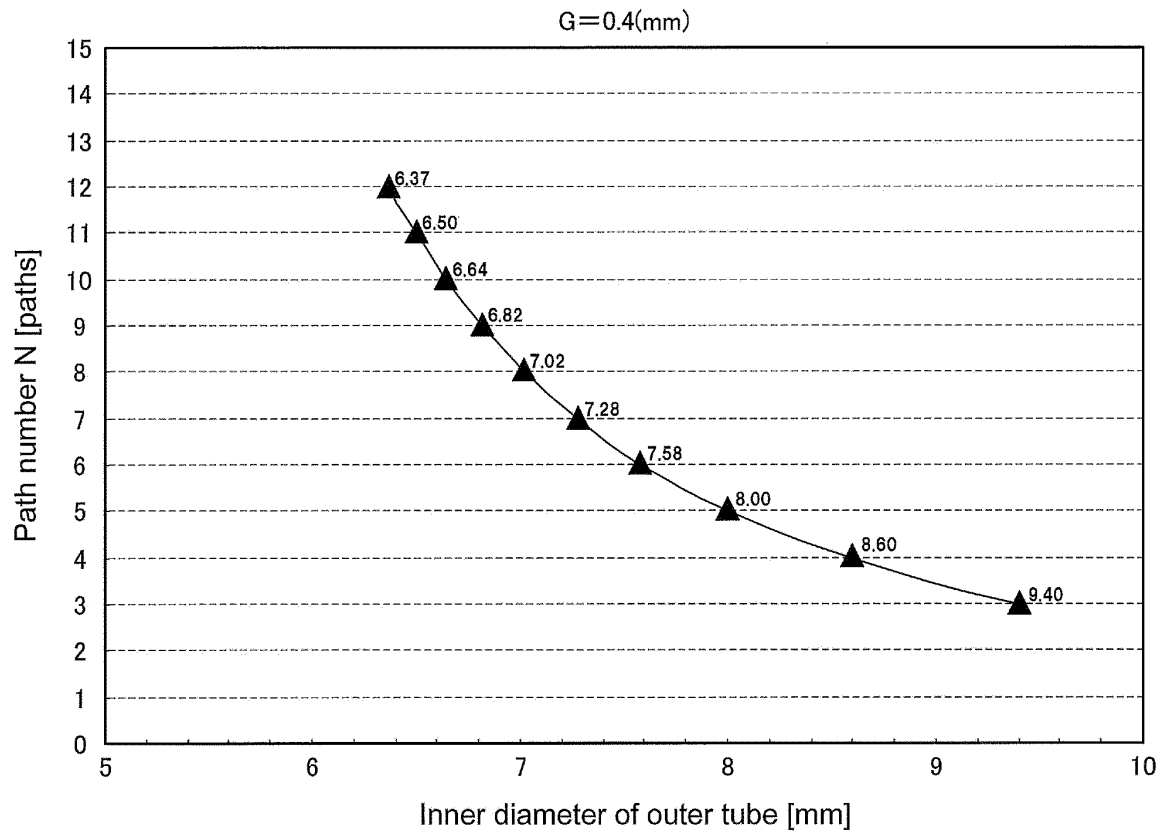


FIG.6

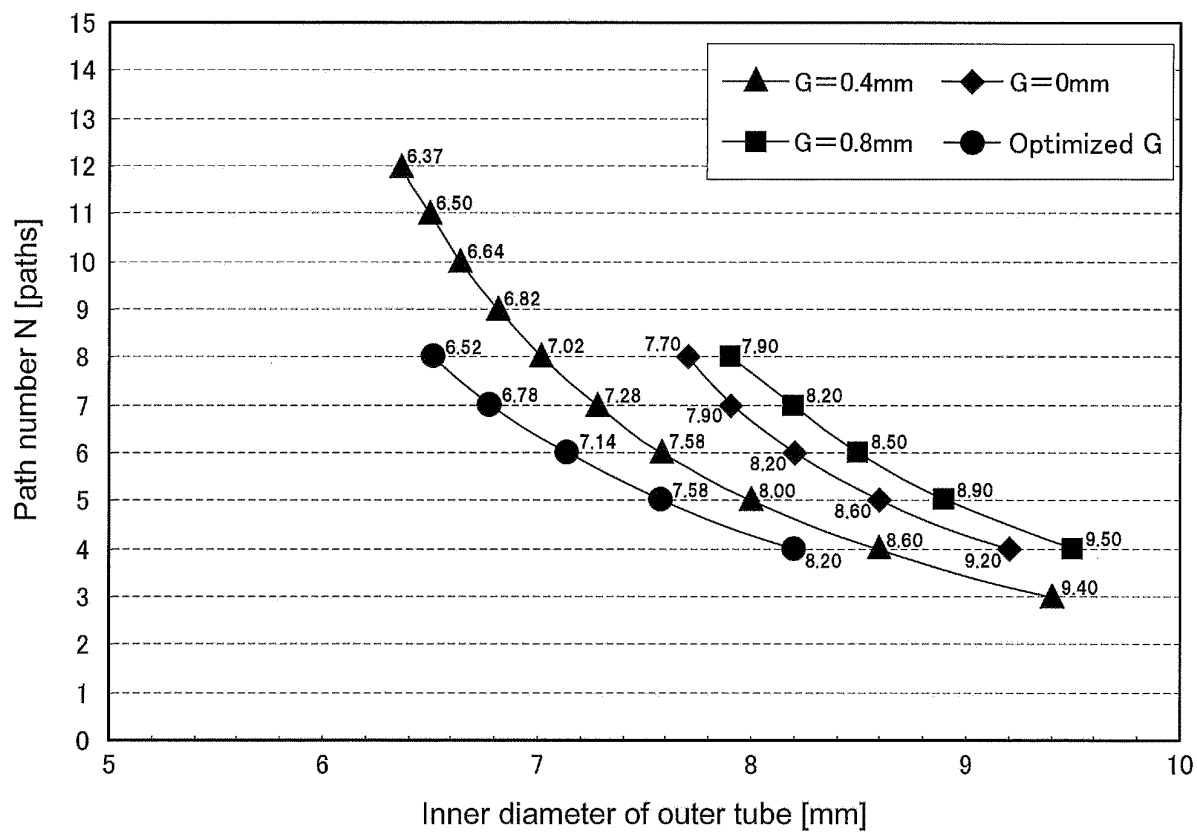


FIG.7

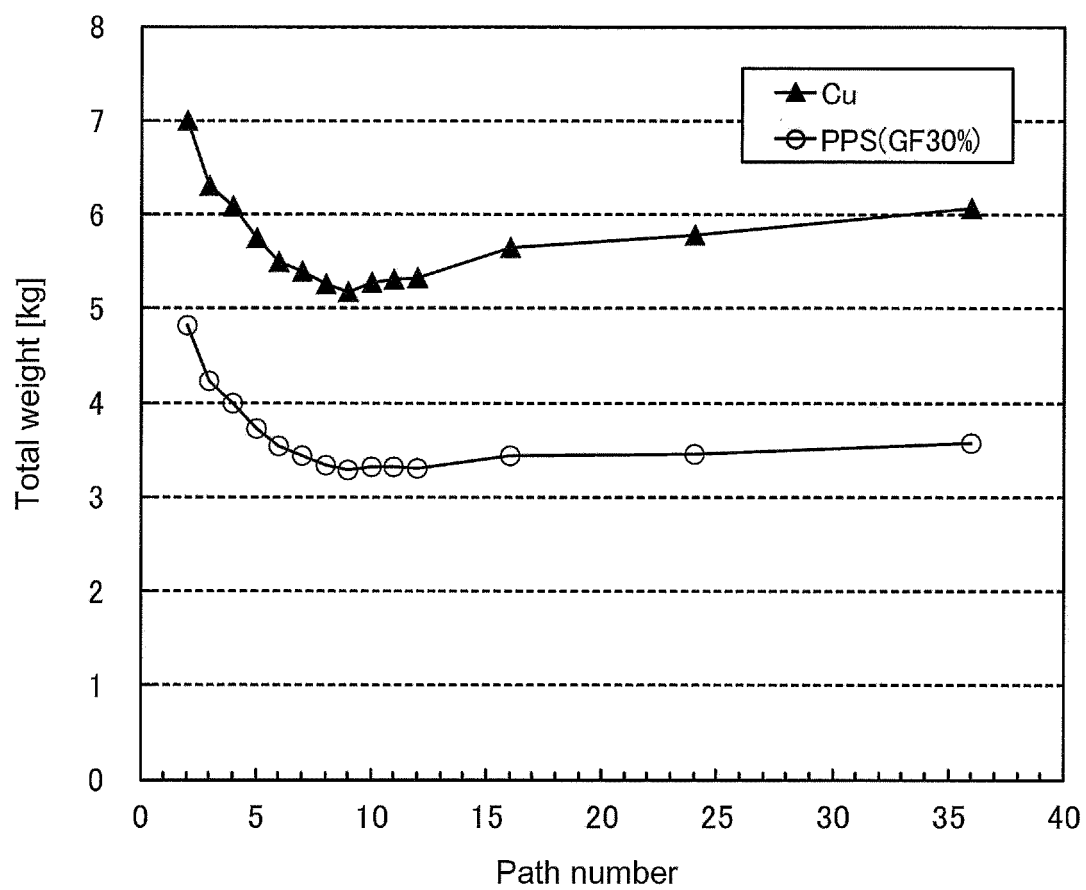


FIG.8

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/004636

A. CLASSIFICATION OF SUBJECT MATTER

F28D7/10(2006.01)i, F28D1/053(2006.01)i, F28F1/00(2006.01)i, F28F9/02(2006.01)i, F28F21/06(2006.01)i, F28F21/08(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F28D7/10, F28D1/053, F28F1/00, F28F9/02, F28F21/06, F28F21/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2004-360974 A (Matsushita Electric Industrial Co., Ltd.), 24 December 2004 (24.12.2004), entire text; all drawings (particularly, paragraphs [0008] to [0010]; fig. 1 to 3) (Family: none)	1-3, 5-7
A	JP 2007-139284 A (Matsushita Electric Industrial Co., Ltd.), 07 June 2007 (07.06.2007), entire text; all drawings (particularly, paragraphs [0039] to [0040], [0054] to [0055]; fig. 1 to 5, 8) (Family: none)	1-3, 5-7

☒ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

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Date of the actual completion of the international search
01 October, 2012 (01.10.12)

Date of mailing of the international search report
09 October, 2012 (09.10.12)

Name and mailing address of the ISA/
Japanese Patent Office

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/004636

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2009-210232 A (Panasonic Corp.), 17 September 2009 (17.09.2009), entire text; all drawings (particularly, paragraphs [0020] to [0035]; fig. 1 to 4, 6) (Family: none)	1, 4-7
A	JP 2008-57859 A (Matsushita Electric Industrial Co., Ltd.), 13 March 2008 (13.03.2008), entire text; all drawings (particularly, paragraph [0031]; fig. 6) (Family: none)	1-3, 5-7
A	JP 2008-274426 A (Kobelco & Materials Copper Tube, Ltd.), 13 November 2008 (13.11.2008), entire text; all drawings (particularly, paragraph [0096]; fig. 2, 4) (Family: none)	1-3, 5-7
A	JP 2005-147567 A (T. RAD Co., Ltd.), 09 June 2005 (09.06.2005), entire text; all drawings (particularly, paragraphs [0022] to [0036]; fig. 1 to 8) (Family: none)	1-3, 5-7

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REFERENCES CITED IN THE DESCRIPTION

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- JP 4414197 B [0006] [0039]
- JP 2005024109 A [0006]